Maine Geological Survey Dept. of Conservation

GEOLOGIC MAP AND CROSS SECTIONS OF THE EASTPORT 15' QUADRANGLE, WASHINGTON COUNTY, MAINE

by

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INTRODUCTION

Edson S. Bastin of the U. S. Geological Survey originally mapped the Eastport quadrangle in 1907-8 and published his report with co-author Henry S. Williams, who described the paleontology, as Folio 192 in 1914. This geologic map is part of a regional study by the Maine Geological Survey of the Silurian and Devonian volcanic rocks of southeastern Washington County. The following brief description is a short guide to understanding the accompanying map. For a summary review of the regional geology of coastal Maine and New Brunswick including other occurrences of Silurian and Devonian volcanic rocks, the reader is referred to Gates (1969), a review, however, which is considerably out of date with recent work by geologists in Maine and New Brunswick.

While mapping the Eastport quadrangle, I have been blessed with the geological wisdom, ideas, and good company in the field of many geologists. Arthur J. Boucot helped collect and identified the brachiopods. Jean M. Berdan collected and studied the ostracodes. W. B. N. Berry identified the graptolites. Robert H. Moench shared with me chemical analyses done by the U. S. Geological Survey in connection with his study of the Pembroke mines. Robert G. Doyle, State Geologist, Walter Anderson, Assistant State Geologist, and Arthur Hussey of Bowdoin College have been very helpful and coopera-tive in many ways. Former students Paul Willette, Donald Brower, and Donald Spalding were able field assistants.

STRATIGRAPHY

A heterogeneous suite of fossiliferous marine volcanic and sedimentary rocks, ranging in age from Early Silurian into Early Devonian, constitute the bulk of the rocks exposed in the Eastport quadrangle. Because the formation names of Bastin and Williams (1914) are well established in the literature, these names are also used on the present map; but a few formation boundaries have been changed, and formation status has been given to the former Leighton gray shale and

Hersey red shale members of the Pembroke Formation (Bastin and Williams, 1914, p. 6-7).

The stratigraphic relations, and relative thicknesses of the various formations and their lithologic units (except the Quoddy) are schematically illustrated in Figure 1.

Silurian System

The Quoddy Formation (Sqs) (Bastin and Williams 1914, p. 3) is confined to the Quoddy fault block southeast of the Lubec fault. Its base is hidden beneath the Bay of Fundy, and its top is a fault contact in the Moose River and Cutler quadrangles adjacent to the southwest.

The lower part of the Quoddy Formation, exposed along the shore from Lubec to West Quoddy Head, consists predominantly of dark gray to black, rusty-weathering, pyritiferous, thinly bedded siliceous siltstone, argillite and shale. Graded laminations, rarely more than an inch thick, of broken feldspar crystals, probably ash falls on the sea floor, are the only evidence of volcanic activity. Southwestward along the shore of Grand Manan Channel and upwards in the formation, volcanic rocks interstratified with siltstone and argillite increase in abundance. They include feldspathic tuff-breccias and lapilli tuffs, a few thin flows of porphyritic, siliceous vitrophyre, and thin basalt flows, some pillowed.

Bastin and Williams (1914, p. 3) reported finding a few brachiopods on the north side of West Quoddy Head near the Coast Guard station. Recent search of the same locality found several species of *Monograptus* to which Berry and Boucot (1970, p. 200) assign a Late Llandovery age.

The Dennys Formation (Bastin and Williams, 1914, p. 3-4) forms the core of the Cobscook anticline north of the Lubec fault. Its base lies in the Gardner Lake quadrangle to the west. Its top is drawn where the vari-colored siliceous tuff-breccias and fossiliferous siltstones of the Edmunds Formation overlie the drab basaltic pyroclastics of the Dennys Formation, a contact about 800 feet higher in the section than that drawn by Bastin and Williams.

The rocks of the Dennys Formation are part of the flank of an explosive basaltic volcano whose deposits extended beneath the sea. Massive to thickly bedded units of coarse basaltic agglomerate, tuff-breccia, and lapilli tuff (Sdbt) attest to explosive eruptions. These are interlayered with well-bedded, waterlaid volcanic sedimentary rocks (Sdt), composed largely of subrounded basaltic clasts with an admixture of more siliceous volcanic components. These bedded rocks include pebble conglomerate, coarse sandstone, and thinly bedded fossiliferous basaltic tuffs, tuffaceous siltstone, argillite, and chert.

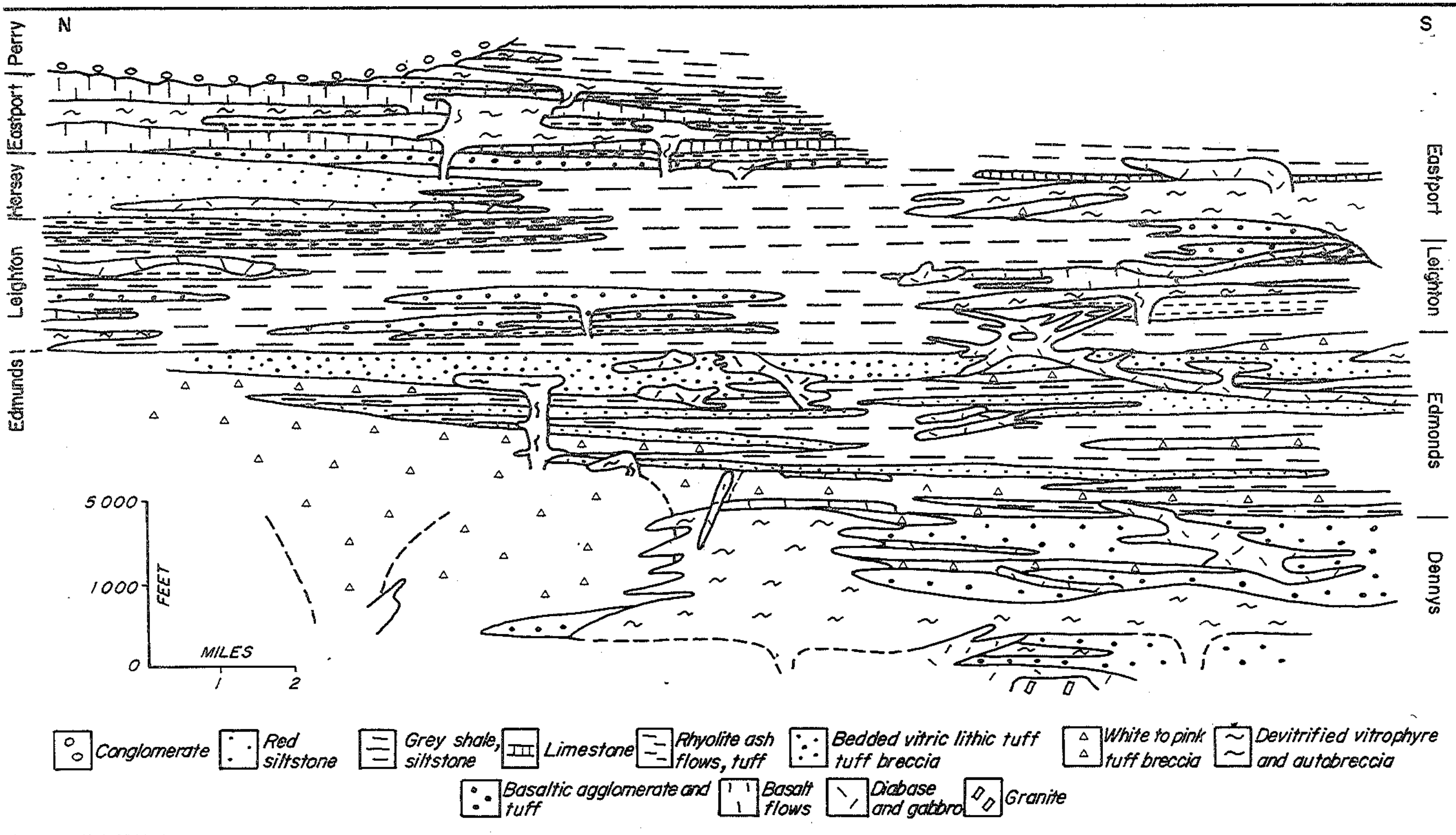

FIGURE I

Schematic sketch illustrating the stratigraphic relations of the Cobscook anticline. From the Dennys formation to the Perry, the line of section moves progressively from west to east following the anticline's eastward plunge. The horizontal and vertical scales are only approximate due to uncertainty about the amount and direction of net slip on many of the strike faults.

The basalt flows (Sdb) originally consisted of labradorite and augite, but hydrothermal alteration has left only remnants of the original minerals. Plagioclase crystals are albitized and saussuritized; chlorite, epidote, and actinolite have replaced most of the pyroxene; and original basaltic glass or fine-grained groundmass is now a mass of intergrown chlorite, epidote, and calcite, which also fill vesicles. The associated basaltic pyroclastic and sedimentary volcanic rocks are similarly altered. Chemical analyses of the two flows give average values of 48.7% SiO_2, 16.7% Al_2O_3, 2.6% Na_2O, and 1.1% K_2O.

A belt of devitrified siliceous vitrophyre (Sdv), probably domes of viscous siliceous magma extruded on the sea floor or shallow intrusions into unconsolidated sediments, occurs in the lower part of the Dennys Formation. The belt is a complex of white or pink, massive or flowbanded, aphanitic, and commonly porphyritic rocks which locally contain lenses and irregular masses of autobreccia, especially near contacts with bedded rocks, suggesting a sharp rise in viscosity as the magma cooled rapidly on encountering sea water or wet bottom sediments.

The mineralogical and textural composition is that of a keratophyre. Phenocrysts of albitized, dusty, unzoned plagioclase lie in a once glassy groundmass now devitrified to a microscopic quartz-feldspathic granular mosaic along with shreds of chlorite. Potash feldspar phenocrysts are absent; quartz phenocrysts occur locally; and there is no evidence of former ferromagnesian phenocrysts. Chemically three vitrophyres average 73.7% SiO_2, 4.8% Na_2O, and 2.8% K_2O, resembling the composition of a sodic rhyolite more than that of a typical soda-rich keratophyre. A fourth analysis yielding 6.4% Na_2O and 1.3% K_2O indicates that typical keratophyres are also present.

The two long lenses of tuff-breccia (Sdtb) within the basaltic rocks of the Dennys Formation are probably pyroclastic debris flows. They consist of angular blocks of siliceous devitrified rhyolitic vitrophyre in a matrix of broken albitized plagioclase crystals, small vitrophyre fragments, and chlorite.

The most diagnostic fossil collections were made just outside the southwest corner of the Eastport quadrangle and consist of a varied fauna of brachiopod genera, several trilobites, corals, and a very few pelecypods. Berry and Boucot (1970, p. 142) assign a Late Llandovery, C_5 through Wenlock age to the Dennys formation.

The <u>Edmunds Formation</u> (Bastin and Williams, 1914, p. 4-6) is well exposed along both shores of Whiting, Dennys, and Straight Bays. Around the nose of the Cobscook anticline, the Edmunds conformably overlies the Dennys; but on the north flank, the characteristic varicolored silicic tuff-breccias of the Edmunds are dirrectly on strike with the basaltic rocks of the Dennys across an intervening belt of flowbanded vitrophyre.

The Edmunds Formation was deposited on the flank of a partially submerged, explosive volcano. Explosive eruptions produced avalanches of pyroclastic debris that spread across a muddy and silty sea floor rich in benthonic life. Streams and ocean currents redistributed and reworked the coarse avalanche deposits to form bedded conglomeratic and sandy pyroclastic sediments. Locally there were a few eruptions of basalt and basaltic pyroclastic rocks. The principal vent may be represented by a mass of vitrophyre and very coarse breccia along the west margin of the map north of Dennysville.

The white, pink, and maroon coarse tuff-breccias of the Edmunds Formation (Setb) are submarine pyroclastic flows or avalanche deposits. They form tongues which thicken to the north and interfinger with fine-grained marine sedimentary rocks to the south. Where the pyroclastic flows moved across soft silty and muddy sediments on the sea floor, the base of the flow cut down into the underlying muds, plastically deformed them, and swept narrow streaks and intricately swirled lenses of mud upwards into the lower 15 or 20 feet of the flow. The tongues of tuff-breccia are composite, made up of several separate debris flows, each having an irregular base that scoured into the top of the underlying flow, a crude grading from large blocks to smaller ones upwards, and commonly a coarsely bedded top where waves and currents reworked the deposit.

The tuff-breccias are lithic crystal pyroclastic rocks consisting of angular blocks and smaller fragments of porphyritic devitrified rhyolitic to dacitic vitrophyre and felsite in an unsorted matrix of broken dusty albitized plagioclase grains, broken quartz grains in some flows, and small fragments of vitrophyre, some basalt, and silicified siltstone and chert. Chlorite, epidote, and calcite are common replacement minerals. Pumice lapilli and shards occur sparingly. Hematite and jasper contribute to the pink and maroon color of many of the Edmunds tuff-breccias. Petrographically the dominant vitrophyre fragments resemble keratophyre, but chemical analysis of three tuff-breccias show a range of 64.9 - 69.5% SiO_2, 3.3 - 4.2% Na_2O, and 1.1 - 3.1% K_2O, about that of dacites. However, the admixture of basaltic fragments probably has reduced the SiO_2 and alkali content.

The bedded tuffs and tuff-breccias (Set) are composed of the same kinds of crystals and rock fragments as the pyroclastic flows but are well-bedded, water-worked and sorted pebble conglomerates displaying lensing beds, cross-bedding, cut-and- fill channel deposits, subrounded clasts, and very little fine-grained matrix. Lenses of maroon tuffaceous siltstone within some of the avalanche deposits and the bedded rocks, suggest that locally, particularly to the north, deposition was subaerial.

The fossiliferous gray to black tuffaceous siltstones, argillite, and chert (Ses) of the Edmunds Formation indicate sedimentation on a rather current-free sea floor between explosive eruptions. They consist largely of silt-sized feldspar and quartz grains, shards, and clays now altered to microscopic flakes of chlorite and white mica.

Thin laminations, graded bedding, and local plastic distortion due to slumping are common.

Mapped as part of the Edmunds Formation are several lense-shaped bodies of siliceous vitrophyre (Sev), some of which are shallow intrusions and others are domes. They consist of pink flowbanded, porphyritic, devitrified rhyolitic vitrophyre, locally autobrecciated. In mineralogy and texture they differ little from the vitrophyric blocks in the tuff-breccias and are of the same general magma type.

With one exception, the few basaltic flows of the Edmunds formation are labradorite-augite basalts, much hydrothermally altered and impregnated with hematite and jasper, which account for their typical maroon color. The one exception is the flow exposed along the west shore of Whiting Bay south of Edmunds. This is an olivine basalt carrying large pseudomorphs of former euhedral olivine phenocrysts. Chemical analyses of three flows average 49.8% SiO_2, 16.3% Al_2O_3, 3.2% Na_2O_3, and .79% K_2O. Near the top of the Edmunds Formation, some of the tuff-breccia avalanche deposits and associated bedded coarse tuff-breccias have a large component of basaltic fragments in addition to vitrophyric components.

The coarse tuff-breccias and associated bedded coarse tuff-breccias thicken and coarsen to the north. A poorly exposed complex (Sebv) north of Dennysville consisting of intrusive rhyolitic devitrified vitrophyre, angular boulders and blocks of vitrophyre, and blocky masses of silicified shale and coarse tuff-breccia may be the principal vent of the Edmunds volcano. A smaller vent at Duck Harbor contains tilted blocks, as much as ten feet across, of bedded tuff-breccia.

On the south limb of the Cobscook anticline, a large dome of pink, flowbanded, siliceous devitrified vitrophyre, autobreccia, and tuff-breccia overlies a much sheared unit of white tuff-breccia with some interstratified shale lenses and basaltic volcanics. This lower unit can be traced as a thinning wedge around the nose of the Cobscook anticline as far as Morong Cove. Apparently during Edmunds time, a second source area of volcanic eruption existed to the southeast.

A series of bulbous tongues of white, pink, and tan porphyritic devitrified vitrophyre (Sdev) with lenses of autobreccia are stacked one above the other west of Edmunds. They separate the largely basaltic rocks of the Dennys formation to the south from the typical white and maroon tuff-breccias of the Edmunds Formation to the north. This stack of vitrophyre probably is a group of domes which were extruded one above the other during deposition of the Dennys Formation and of the lower part of the Edmunds. They acted as a barrier between the flank of the basaltic Dennys volcano and that of the silicic Edmunds volcano. Eventually the deposits of the Edmunds volcano overtopped the pile of domes and spread southwards across the flank of the less active Dennys volcano.

The tuffaceous siltstones and shales of the Edmunds Formation carry an abundant and diversified benthic fauna. Brachiopods predominate, and compared to the brachiopod fauna of the Dennys Formation, have more individuals but fewer genera. Pelecypods and gastropods are also numerous. The remaining fossils include trilobites, corals, ostracodes, and orthoceroids. Berry and Boucot (1970, p. 145) assign a Ludlow age to the Edmunds Formation.

The Leighton Formation is the former Leighton gray shale member of the Pembroke Formation (Bastin and Williams, 1914, p. 6-7). Its base is drawn where its typical gray shales and fine-grained tuffs carrying the characteristic Salopina fauna overlie the varicolored pyroclastic rocks of the Edmunds. On Leighton Neck, a quartz porphyry tuff that grades upwards into the maroon mudstones of the Hersey Formation marks the top of the Leighton. The Leighton Formation underlies Leighton Neck and continues southward to Denbow Neck where it undergoes a marked facies change.

On Leighton Neck, most of the Leighton Formation consists of gray and glue-gray, somewhat limey, siltstone and shale (Sls). Lenses and elongate nodules of limestone within bedding, thin lensing beds, and irregular wavey contacts between beds are typical. Near the base of the Leighton Formation, the typical siltstones and shales interstratify with siliceous well-bedded tuffs and tuffaceous siltstones containing pumice lapilli and feldspar crystals, indicative of ash falls. Outpourings, apparently through vents in the sea floor, of coarse basaltic tuff-breccia and lapilli tuff (Slbt) produced thick lenses whose upper surfaces and margins were reworked by waves and currents. Thin basalt flows, (Slb), also apparently erupted through the sea floor, overlie some of the basaltic tuffs. Several thin submarine pyroclastic flows (Slt) moved across the muddy sea floor churning up and incorporating the underlying muds. These pyroclastic debris flows consist of broken quartz and albitized plagioclase crystals, shards, pumice lapilli and abundant fragments of silicified shale and argillite.

On Denbow Neck, the typical gray shales of the Leighton Formation pinch out between tongues of volcanic rocks. The latter include bedded rhyolitic vitrophyric and basaltic tuffs overlain by an elongate dome of rhyolitic devitrified vitrophyre which in turn is overlain by a section of bedded basaltic tuffs, thin lava flows, and coarse basaltic agglomerate and tuff-breccia. These volcanic rocks thicken to the southeast, indicating a source in that direction.

The fauna of the Leighton Formation is a restricted one, easily recognized in the field. It consists of rhynchonellid brachiopods, a few other brachiopods, and abundant individuals of the genus Salopina, together with numberous gastropods, pelecypods, ostracodes, and a few trilobites. Berry and Boucot (1970, p. 104-106) name the brachiopod element of this fauna the Salopina community. The ostracode fauna associated with the Salopina community in Maine and New Brunswick indicate a latest silurian (Pridoli) age (Berdan 1971, p. 18; Berry and Boucot, 1970, p. 196).

The Hersey Formation (Shs), formerly the Hersey red shale member of the Pembroke Formation (Bastin and Williams, 1914, p. 7), conformably overlies the Leighton Formation on Hersey Neck but is absent east of Denbow Neck where its stratigraphic position is occupied by shales, basaltic rocks, and vitrophyre assigned on lithologic grounds to the Eastport Formation. The facies change occurs beneath Cobscook Bay. The upper contact with the Eastport Formation west of Perry is gradational through a zone of interfingering maroon tuffaceous siltstone, gray shale, and basaltic flows and tuffs.

Dark maroon siltstone and mudstone characterize the Hersey Formation. Several lenses of gray shale, resembling the Leighton shales, interfinger with the Hersey redbeds in Hersey Cove and the north arms of Sipp Bay, and pinch out to the northwest. Near the top there are several beds of knobby pink limestone; and small limey nodules occur in several places throughout the formation. The Hersey is probably a mudflat or very shallow estuarian deposit.

The fauna is a restricted, probably shallow or brackish water, one of pelecypods, gastropods, and ostracodes, without brachiopods. The ostracode fauna suggests that the Silurian-Devonian boundary may lie within the Hersey Formation (Berdan, 1971, p. 18), but the exact location of the boundary is not yet settled.

Poorly exposed rocks labelled Silurian Undifferentiated (Su) occur in the Mt. Tom area in the northwest corner of the map. The few outcrops of black shale, argillite, and bedded feldspathic tuff are insufficient to assign the rocks to any of the Silurian formations on lithologic grounds. Bastin and Williams (1914, p. 3) reported finding a *Monograptus* sp. indet. in a railroad cut of black shale, and assigned the rocks to the Quoddy Formation. This required a northeast trending fault separating the presumed Quoddy from rocks Bastin mapped as Dennys but considered to be Edmunds on the present map. A thorough search of the same railroad cut failed to find any graptolites. However, on the basis of Bastin's single find, the rocks are labelled Su and the fault drawn by Bastin is included on the present map.

Devonian System

The Eastport Formation (Bastin and Williams, 1914, p. 7-9) overlies the Hersey Formation gradationally north of Cobscook Bay and on Seward Neck is in part the stratigraphic equivalent of the Hersey Formation. An angular unconformity separates it from the overlying fluvial red clastic rocks of the Perry Formation. Eruptions of basaltic rhyolite andesite lavas and coarse pyroclastics alternated with eruptions of silicic tuff-breccias, ash flows, volcanic domes, and shallow intrusions. North of Route 1 volcanism was subaerial. Along the shore of Cobscook Bay and on Moose Island, the lavas, tuffs and ash flows spread across a shallow sea floor, at times rising above sea level. On Seward Neck, the Eastport Formation is wholly marine.

North of Route 1 where the Eastport Formation overlies the Hersey, the lowermost rocks are thin basaltic andesite flows (Deb) and thickly bedded basaltic agglomerates and tuff-breccias (Debt) interlayered with tuffaceous maroon siltstones. To the southeast along the shore of Cobscook Bay, this lowermost basaltic andesite sequence interfingers with maroon, gray, and black siltstones (Des) some of which contain marine fossils. A thick series of basaltic andesite flows, which thin to the southeast, overlies the lowermost flows and pyroclastic rocks. North of Route 1, many of the basaltic andesite flows exhibit dark red weathered flow tops, locally overlain by red mudstone. A second sequence of basaltic andesite lavas occurs near the top of the Eastport Formation. The southern end of Moose Island consists of almost flat-lying flows. At Buckman Head basaltic andesite lava erupted into soft black muds, forming a spectacular display of large bulbous bolsters, as much as 10 feet in diameter, and smaller pillows, surrounded by thin screens of plastically deformed silicified shale full of lava chips.

The basaltic andesite lavas of the Eastport Formation consist of labradorite and augite; textures are intergranular to subophitic; some flows have large euhedral phenocrysts of slightly zoned labradorite; and most flows are highly vesicular, especially near the tops. No columnar jointing is apparent. All the lavas have been hydrothermally altered to albitized and saussuritized feldspars, chlorite, epidote, and calcite. Many flows are maroon from oxidation of magnetite to hematite, and thin seams of jasper are common. The basaltic pyroclastic rocks have the same general mineralogy and hydrothermal alteration. Chemical analyses of five flows average 52.1% SiO_2, 15.9% Al_2O_3, 3.8% Na_2O, and 1.0% K_2O.

Several units of pink to maroon rhyolitic ash flows (Devt) occupy the middle part of the Eastport Formation. These are composed of devitrified shards, pumice lapilli, and vitrophyre fragments plus broken quartz, albitized plagioclase, and minor potash feldspar crystals. Collapsed pumice, a general parallel orientation of shards, and the wrapping of shards over and under mineral crystals suggest that some of these ash flows are welded tuffs.

The middle part of the Eastport Formation also contains several sills of massive to flowbanded porphyritic vitrophyre and a thick, wedge-shaped intrusive mass of highly flowbanded devitrified rhyolitic vitrophyre. The north boundary of this mass is almost vertical and bordered by contorted, generally vertical flowbanding in the vitrophyre. To the south the vitrophyre wedges out and flowbanding approximately parallels the floor and the roof. Zones of auto-breccia occur within this wedge-shaped intrusion. The magma must have been very viscous and dry to have remained vitreous as it cooled. The uppermost sedimentary rocks of the Eastport Formation are intruded by numerous dikes and sills of the same pink devitrified rhyolitic vitrophyre.

Chemical analyses indicate these vitric tuffs and flow-banded vitrophyres are largely rhyolites although quartz and potash feldspar phenocrysts are much less common than plagioclase. Four analyses average 74% SiO_2, 4.2% Na_2O, and 3.8% K_2O.

The uppermost rocks of the Eastport Formation are best exposed on the north shore of Moose Island. They are fossiliferous gray, green, and maroon well-bedded siltstones, shales, and sedimentary breccias. Ripple marks, cross-bedding, current-cut-and-filled channels, uneven bedding, limey nodules that may be algal, and mudcracks indicate deposition in shallow water, perhaps on mudflats or in a shallow estuary.

Redoubt Hill on Moose Island near Kendall Head, is a roughly circular pipe filled with coarse basaltic and rhyolitic breccias which include fragments of siltstone and silicified shale. It may have been a vent for younger Eastport volcanic rocks now removed by erosion, since the vent cuts the shales and the siltstones that are the youngest bedded rocks presently preserved.

On Seward Neck, a thick tongue-like mass of flowbanded vitrophyre, autobreccia, and tuff-breccia locally transects underlying basalt flows, pyroclastics, and silicified shales at low angle, and is overlain by fossiliferous cherty limestone and black shale. This is a large composite rhyolitic dome extruded across the sea floor from a source to the southeast.

The rocks of the long narrow block between the Lubec fault and the south limb of the Cobscook anticline are presumed to be Eastport Formation, based on gross lithologic character gleaned from a few widely scattered outcrops; and the stratigraphy and structure shown on the map in this block represents the most logical of several ways to interpret the pattern of the sparse outcrops.

Lingulids, pelecypods, gastropods, and several new genera of ostracodes (Berdan, 1971, p. 18) constitute the restricted fauna of the Eastport Formation. Its stratigraphic position above the Hersey and Leighton Formations and the affinity of its new ostracode genera to somewhat similar forms in Europe suggest a Gedinne or later Devonian age (Berdan, 1971, p. 18; Berry and Boucot, 1970, p. 144; A. Martinsson, 1970, p. 43).

The <u>Perry Formation</u> (Smith and White 1905; Bastin and Williams 1914, p. 9-10; Schluger 1973) rests with angular unconformity on the Eastport Formation in a large area north of Perry, on the Eastport Formation in several fault blocks south of Perry, on the Hersey Formation on Hersey Neck, and on Leighton Formation on the south flank of the Cobscook anticline.

The Perry Formation (Dpc, Dpm) is largely a terrestrial and fluvial deposit consisting of red and maroon coarse boulder and pebble conglomerate, arkosic sandstone, siltstone, and mudstone. Schluger (1973) has identified scree, alluvial fan, overbank, and lacustrine facies. Boulders and cobbles are of the underlying Silurian-Lower Devonian volcanic rocks and of a red, fine-grained granite identical to the Red Beach granite (Amos 1963) exposed along the shore of the St. Croix River about ten miles north of Perry. In the fault block on Hersey Neck and the one along the north shore of Bar Harbor, coarse boulder conglomerate occurs along the bounding faults and thins rapidly as a wedge away from the fault, suggesting deposition of the Perry clastic rocks in active fault basins.

One lava flow (Dpb) in the Perry Formation is exposed along the shore of Passamaquoddy Bay in the Eastport quadrangle. The flow is composed of a much hydrothermally altered, labradorite-augite amygdaloidal basalt. It contains 48.9% SiO_2, 15.8% Al_2O_3, 3.9% Na_2O, and .70% K_2O.

Plant remains are the only fossils that have been found in the Perry Formation. Smith and White (1905, p. 35), Bastin and Williams (1914, p. 10), and Schluger (1973, p. 2540) agree on a Late Devonian age based on the flora.

The Perry Formation is a post-orogenic fluvial and lacustrine deposit laid down in fault troughs following deformation and uplift of the underlying rocks during the Acadian orogeny. The Early Devonian age for the Eastport Formation and the Late Devonian age for the Perry serve as bracketing ages for the time of the Acadian orogeny in this part of New England and southern New Brunswick. Fullagar and Bottino (1970, p. 51) report a 408$\pm$3. m.y. isotopic age for the Eastport Formation based on Rb/Sr whole rock analyses of some of the Eastport vitrophyre. A K/Ar age of 401 m.y. (Faul and others, 1963, p. 7) and a Rb/Sr age of 400 m.y. (Spooner and Fairbairn, 1970, p. 3666) have been determined for the Red Beach granite which intrudes the Eastport Formation on the St. Croix River north of Perry, rounded cobbles of which occur in the Perry Formation.

INTRUSIVE ROCKS

Diabase and gabbro (d) intrude all the formations of the Eastport quadrangle from the Quoddy to the Eastport. It is likely that basic intrusive activity accompanied basaltic volcanism throughout the deposition of the volcanic formations. From late Early Silurian to Early Devonian time the Eastport area must have been underlain by a continuing source of basaltic magma.

The plentiful gabbro and diabase that intrudes the Quoddy Formation is a continuation of the Cutler Diabase in the Moose River and Cutler quadrangles to the southwest (Gates, 1961, p. 32-46).

Multiple injections of basic magma bounded by chill zones or thin screens of Quoddy sedimentary rocks have produced sills and sill-like subconformable tabular plutons, some of which are 800 feet thick. These thin and finger out to the southeast in narrow tabular lenses parallel or nearly so to the bedding in the intervening Quoddy siltstone and argillites. Intrusion of some of the basic magma must have been almost contemporaneous with deposition of the Quoddy Formation while the silts and muds of the ocean floor were still unconsolidated. Many of the lenses have bulbous contacts with plastically deformed and silicified siltstone and argillite. Along the contacts, the diabase has a narrow chill zone bordered by a belt of vesicles, much like in pillow lavas, and the adjacent shale contains pumice fragments and angular chips of glassy basalt which apparently spalled off the magma as it rapidly chilled in the wet muds.

North of the Lubec fault, diabase and gabbro form numerous dikes, (only the largest of which are shown on the map), sills and irregular small plutons with a variety of shapes. The basic magma tended to spread out in the bedded rocks, producing subconformable, tongue-like intrusions.

Labradorite and augite are the essential minerals, ranging in proportion to each other from 55-70 percent plagioclase to 45-30 percent pyroxene. Titaniferous magnetite is the principal accessory mineral along with sphene. Textures are ophitic, subophitic, and intergranular; and some of the large plutons and sills have irregular stringers and clots of coarse pegmatitic gabbro. A few intrusions having a fine-grained, felty, subtrachytic texture and little pyroxene are probably more siliceous and alkalic than the typical diabase, but these have not beem mapped separately.

Hydrothermal alterations, as in the volcanic rocks, is almost ubiquitous. Only in the centers of a few large intrusions is the original mineralogy still intact. Labradorite has been albitized and saussuritized, augite replaced by chlorite, and magnetite partially oxidized to hematite. Calcite and epidote are widespread, both replacing the rocks or as crosscutting veins.

Chemical analyses of two gabbros south of the Lubec fault give averages of 47.8% SiO_2, 15.7% Al_2O_3, 2.5% Na_2O, and .9% K_2O. No evidence of former olivine was found in thin-sections.

A small area of granite (gr) intruding the Dennys Formation is exposed at the west edge of the quadrangle. It is the east margin of a small stock in the Gardner Lake quadrangle. In the Eastport quadrangle the granite is a granophyre composed of quartz and orthoclase micrographically intergrown and enclosing small euhedral crystals of oligoclase. Most of the stock in the Gardner Lake quadrangle is of hornblende-biotite quartz monzonite.

The Mt. Tom basaltic andesite (a) (Bastin and Williams, 1914, p. 12) has an upper intrusive contact with hornfelsed shales and argillite that dips to the east and is exposed along the west shore of Pennamaquan Lake about a mile north of the quadrangle. Its south contact is vertical. It may be a trap-door intrusion. The rock is so hydrothermally altered that its original mineralogy is speculative. Euhedral albitized and saussuritized plagioclase phenocrysts are set in a fine-grained groundmass of similarly altered plagioclase laths, chlorite, epidote, and partially oxidized magnetite. A few clots of chlorite, epidote, and calcite may represent original ferromagnesium phenocrysts, perhaps pyroxene. Chemically and texturally the Mt. Tom basaltic andesite resembles the basaltic andesite flows of the Eastport Formation and may have been a feeder stock for the latter.

The AMF diagram (figure 2) summarizes the chemistry of the Silurian and Lower Devonian volcanic rocks of the Eastport area. The Silurian (Dennys, Edmunds, Leighton, and Cutler diabase of Quoddy age) rocks and the Lower Devonian rocks of the Eastport formation form two distinct suites, both strongly bimodal. The Silurian assemblage appears to have a typical calc-alkaline trend, except that andesites are absent but for one dike that intrudes the Dennys Formation. How much of the trend towards the alkali corner reflects the addition or subtraction of alkalies by hydrothermal alteration is unknown. The gap in SiO_2 content ranges from 53.5 to 68.4 percent except for the single dike. The volcanic rocks of the Eastport Formation have a strong iron-enrichment trend and are more alkalic than those of the Silurian suite. The SiO_2 gap is from 65.6 to 69.0 percent. The basalt of the Perry Formation may be of a third magma type but one analysis is not diagnostic.

METAMORPHISM

The volcanic and intrusive rocks of the Eastport quadrangle, including the basaltic lava in the Perry Formation, have been partially altered to the minerals of the greenschist facies - chlorite, albite, epidote, and actinolite, plus calcite. The preservation of original textures and of parts of the original minerals, the presence of detrital grains of epidote in some of the clastic volcanic rocks, local variations in the completeness of the alterations, and the widespread oxidation of the volcanic rocks of the Edmunds and Eastport Formations indicate that this metamorphism was hydrothermal, some of it near the surface, and contemporaneous with the volcanism.

During the Acadian orogeny, low-grade metamorphism produced chlorite and fine-grained muscovite in the cleavage planes of the Lubec fault zone and adjacent belts of highly sheared rocks, and locally in the northeast trending fracture cleavage that transects most of the Eastport quadrangle, particularly in the relatively incompetent siltstones, shales, and fine-grained tuffaceous sedimentary rocks.

A local metamorphism accompanied the post-Devonian strike slip faulting in the Lubec fault zone, the adjacent narrow block of Eastport Formation, and the south flank of the Cobscook anticline. Near these faults the rocks were highly sheared accompanied by growth of chlorite and fine-grained muscovite or biotite parallel to the shear planes.

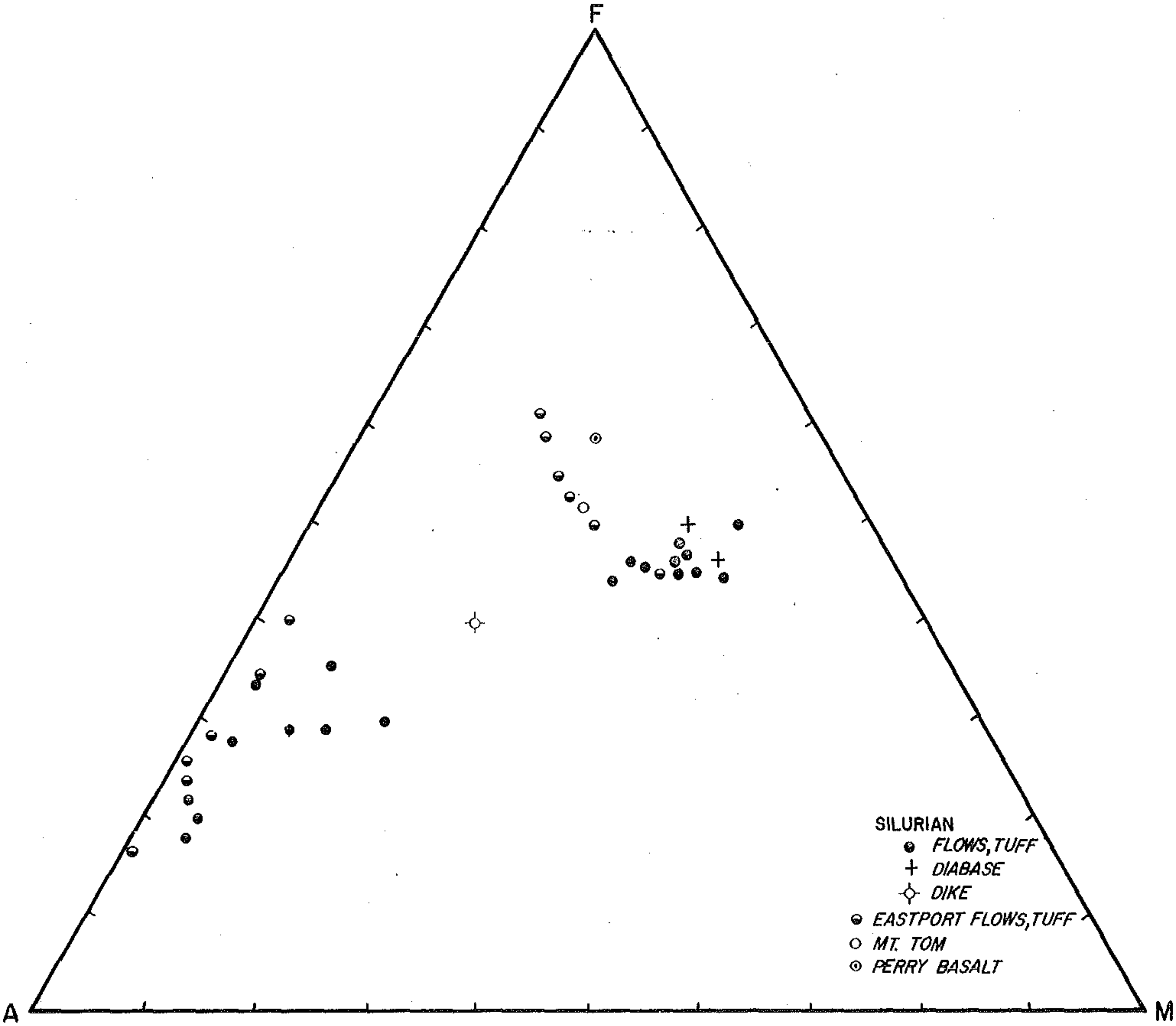

FIGURE 2

A M F diagram of the volcanic rocks of the Eastport area. "A" is $K_2O + Na_2O$; "F" is $FeO + .9 Fe_2O_3$; "M" is MgO: weight percent. Analyses by the U. S. Geological Survey.

STRUCTURE

The principal structural elements of the Eastport quadrangle in order from south to north are: The Quoddy fault block, the Lubec fault, a narrow faulted syncline of presumed Eastport Formation, the Cobscook anticline, and to the northeast, the Perry syncline.

Two approximately parallel faults bound the Quoddy fault block, the presumed Fundian fault (Johnson, 1925, p. 286-294; Gates, 1969, p. 500) offshore parallel to the shoreline, and the Lubec fault on the northwest. A broad open anticline and syncline plunging to the southwest and a fracture cleavage that strikes parallel to the folds and dips vertically or nearly so are the main structural features within the block.

The Lubec fault (Bastin and Williams, 1914, p. 13) is a northeast-trending zone of poorly exposed, highly sheared rocks of the Quoddy Formation and associated diabase. It is a major fault bringing the Quoddy Formation against the Eastport, an apparent displacement of at least 30,000 feet. Closely-spaced fracture cleavage and the axial planes of local isoclinal folds dip vertically or steeply to the southeast. Slickensides, mullions, boudons, and mineral streaking plunge down the dip of the cleavage planes. The plunge of the isoclinal folds ranges between 0-30 degrees in northeast or southwest directions. Growth of muscovite and chlorite parallel to the cleavage has converted the argillaceous rocks to fine-grained muscovite phyllites and the margins of diabase intrusions to chlorite phyllites. Veins of calcite and quartz are common where gabbros have been sheared and brecciated.

A narrow synclinal block of presumed Eastport Formation borders the Lubec fault on the north. It too has been highly sheared and brecciated. Several northeast-striking, vertical faults, some of which merge with the Lubec fault, offset the synclinal block and the adjacent south limb of the Cobscook anticline.

The Cobscook anticline has a homoclinal north limb along which dips average about 20 degrees to the northeast. The south limb dips as much as 80 degrees to the southeast towards the Lubec fault. The axis plunges to the east-northeast, converging with the northeast trend of the Lubec fault. On this steep south limb, thin shale lenses display isoclinal folds with approximately horizontal axes and an axial plane cleavage that dips 80 degrees or more to the southeast. Even some of the relatively competent vitrophyres and tuff-breccias are strongly sheared.

Northeast of the Cobscook anticline, an open syncline of Eastport Formation, the Perry syncline, plunges gently to the north, almost at right angles to the plunge of the Cobscook anticline. A major fault, the Oak Bay fault underlies Western Passage (Cummings, 1967, p. 12) and separates the rocks of the Eastport Formation on Moose Island from steeply dipping and foliated argillaceous rocks of presumably older age on the west shore of Deer Island.

A persistent fracture cleavage that strikes northeast to east-northeast and ranges in dip from vertical to about 60 degrees southeast obliquely transects the rocks of the Cobscook anticline and Eastport syncline throughout the quadrangle, except the rocks of the Perry Formation. On the south limb of the Cobscook anticline it swings a few degrees towards the east and parallels the trend of the Cobscook anticline. It also has been rotated locally along faults and small drag folds associated with faults in other parts of the quadrangle.

The northeast-striking faults that cut the Eastport Formation in the Perry area also displace the Perry Formation. These faults are vertical or nearly so and drop the Perry clastic rocks downwards in small grabens or tilted fault blocks. Coarse Perry conglomerates that thin rapidly away from some of these faults suggest the latter were active fault scarps being eroded as the Perry was deposited. The Perry Formation in the large area of outcrop north of Perry has been gently warped as well as faulted.

Several faults that strike northwest offset the rocks of the Edmunds, Leighton, and Hersey Formations. Horizontal Slickensides on several of these faults and the apparent displacement of lithologic units, particularly in the Leighton and Hersey Formations, suggest right-lateral, strike slip movement. Several of these faults, notably the one near the base of the Leighton Formation, and the one which largely underlies Whiting Bay, appear to have been folded with the rocks of the Cobscook anticline and hence are of Acadian or older age.

Evidence for the presumed fault near Ayers Junction in the northwest corner of the quadrangle has been described on page 8.

The initial structure of the Eastport quadrangle may have been an open northerly trending syncline of which the Perry syncline is a remnant. Uplift of the Cobscook anticline refolded the southwest side of this initial syncline, forming at the same time a narrow syncline of Eastport rocks, perhaps a continuation of the Perry syncline. The map pattern suggests the south limb of the Cobscook anticline resulted from drag by right-lateral movement on the Lubec fault. However, the orientation of the cleavage, isoclinal fold axes, slickensides, and mineral streaking on the cleavage planes in the Lubec fault zone and on the south limb of the Cobscook anticline indicate penetrative movement that was vertical or steeply dipping to the southeast, presumably the result of a southeast-northwest oriented compression.

The folding that formed the Cobscook anticline and neighboring narrow syncline of Eastport rocks reflects the Acadian orogeny. Near the head of South Bay, a small remnant of Perry conglomerate and mudstone rests with angular unconformity on steeply dipping beds of the Leighton Formation on the south limb of the Cobscook anticline. The regional fracture cleavage is also of Acadian age as it does not cut the Perry Formation. No system of northeast trending folds associated with this regional northeast cleavage was found in the Eastport quadrangle. Brown (1972) reports two phases of Acadian folding of Silurian-Lower Devonian volcanic rocks in southern New Brunswick.

The age of the Lubec fault and its relationship to the Cobscook anticline are not clearly evident. The close juxtaposition of the Lubec fault with the narrow syncline of Eastport rocks and with the south limb of the Cobscook anticline, and the parallelism of their penetrative structures can be explained most simply by assigning them all to the same deformation of Acadian age, the uplift of the Quoddy block occurring along a steep reverse fault in response to an Acadian southeast-northwest oriented compression. On the other hand, the Lubec fault is very probably a continuation of the large Belleisle fault in the New Brunswick whose age is post-early Carboniferous (Webb, 1969, Brown, 1973); and in the Eastport quadrangle, the Lubec fault apparently truncates the south limb of the Cobscook anticline, suggesting it is younger than the latter.

The east-northeast faults that cut the Lubec fault, the narrow syncline of Eastport Formation, and the south limb of the Cobscook anticline appear (exposures are poor) to offset the small remnant of Perry Formation near the head of South Bay. These faults thus are probably post-Devonian in age. Horizontal slickensides on several of these faults and offsets of the lithologic units they cut suggest right-lateral strike-slip displacement. Webb (1969) presents evidence for large right-lateral displacements on the throughgoing northeast-striking faults of New Brunswick of which the Belleisle is one. On the other hand, Brown and Helmstaed (1970) and Brown (1972) find evidence in the penetrative structures along the Belleisle fault only for high angle thrust movement.

SUMMARY

The rocks of the Eastport quadrangle portray a history of continuous, dominantly explosive, largely marine volcanism from late Early Silurian into Early Devonian time. Initial volcanism during deposition of the lower part of the Quoddy Formation was in water deeper than wave base or than the habitat of a benthic fauna. Subsequently throughout the rest of the Silurian the sea gradually became shallower, waves and currents reworked and distributed many of the volcanic deposits, and the benthic fauna became increasingly specialized towards shallow water forms. By Eastport time in the Early Devonian, the northern third of the quadrangle was land and the sea to the south was very shallow.

The volcanic and hypabyssal intrusive rocks fall into two groups, basic and silicic. Petrographically, the basalts resemble spilites and the siliceous vitrophyres resemble keratophyres. On the other hand, although soda exceeds potash in most of the volcanic rocks, the excess is not of the extent typical of the spilite-keratophyre eugeosynclinal suite. The coarse pyroclastic rocks suggest explosive eruptions common for andesitic volcanoes, but both the chemical content and the petrology indicate the typical andesites are absent, although a few tuff-breccias in the Edmunds Formation of mixed vitrophyric and basaltic components approach andesites chemically.

The volcanic rocks of the Dennys Formation probably came from a basaltic vent somewhere in the adjacent Gardner Lake quadrangle to the west. The Edmunds, Leighton, and Eastport Formations have tongues and lenses of volcanic rocks which flowed, avalanched, or were washed from vents to the south or southeast and from vents to the north or northwest into an intervening shallow marine basin of silty and muddy tuffaceous sediments. The great thickness of the entire section, at least 30,000 feet, suggests that subsidence accompanied the volcanism. Perhaps the volcanic and sedimentary rocks of the Eastport quadrangle accumulated in a subsiding submarine graben or large submerged subsiding caldera from vents along marginal bounding faults.

The Acadian orogeny in the Middle Devonian ended the explosive volcanism and produced folding, faulting, and a regional fracture cleavage accompanied by growth of fine-grained mica in the cleavage planes, but the rocks were not deeply buried and regionally metamorphosed. Post-Acadian uplift and block faulting in the Upper Devonian led to fluvial deposition of the Perry Formation, accompanied by extrusion of basalt in local fault basins. Final movement in the Lubec fault zone was right-lateral and post-Devonian age, but the age of the principal displacement that brought the Quoddy Formation against the Eastport is an unsettled question.

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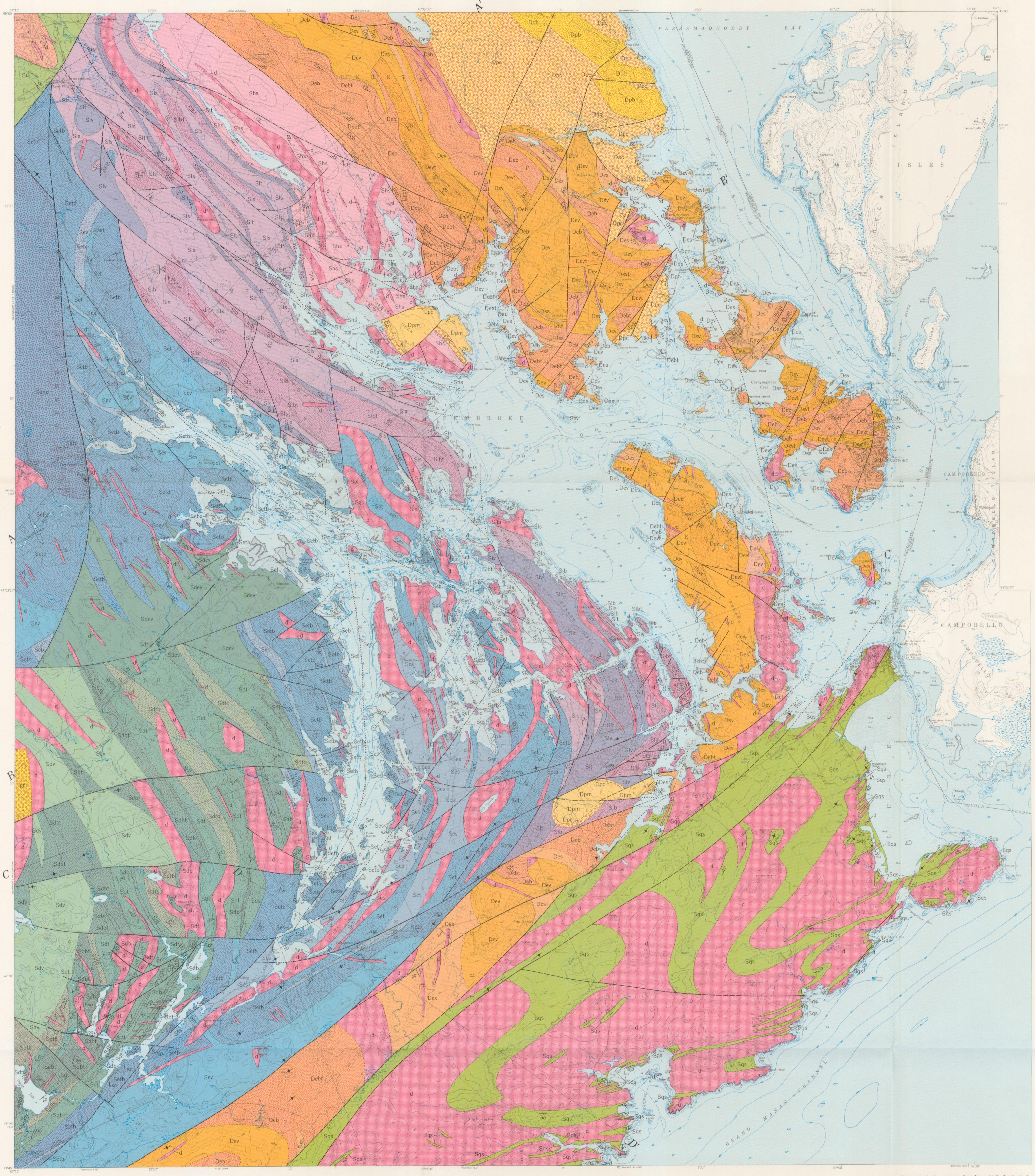

Williams & Heintz Map Corporation, Washington, D.C. 20027

Topographic base compiled from U.S. Geological Survey 7½′ quadrangles. Geology by Olcott Gates, Paul Willette, Donald Brower, and Donald Spalding, 1961-1971.

EXPLANATION

U. DEVONIAN

PERRY FORMATION

Dpc — *Maroon cobble and pebble alluvial conglomerate and arkosic sandstone. Clasts of underlying volcanic rocks and granite.*

Dpm — *Red sandstone, siltstone, and mudstone. Plant fossils.*

Dpb — *Basalt flows.*

UNCONFORMITY

L. DEVONIAN

EASTPORT FORMATION

Des — *Grey, green, locally maroon siltstone and shale. A few conglomerate lenses. Ostracodes, pelecypods, gastropods, lingulas.*

Devt — *Massive to well bedded vitric lithic tuff and tuff breccia. Rhyolite, hydrothermally altered. Collapsed pumice and shards suggest some may be welded ash flows.*

Del — *Cherty thinly bedded limestone. Ostracodes.*

Debt — *Green and maroon basaltic tuff breccia, agglomerate, and lapilli tuff. Massive to well bedded. Local red mudstone beds.*

Dev — *Devitrified vitrophyre and autobreccia. Rhyolite. Hydrothermally altered. Domes, dikes, and concordant lenses.*

Deb — *Black, maroon, basaltic andesite flows, some with local red weathered tops and red mudstone beds between flows. Altered to chlorite, epidote, albite.*

SILURIAN

HERSEY FORMATION

Shs — *Maroon and green siltstone, mudstone and shale, locally calcareous. Ostracodes, pelecypods, gastropods.*

Eastport formation on Seward Neck age equivalent of Hersey formation.

LEIGHTON FORMATION

Sls — *Grey siltstone, mudstone, and shale. Locally calcareous or tuffaceous. Brachiopods, ostracodes, pelecypods, gastropods.*

Slt — *Lithic crystal lapilli tuff and tuff breccia. Rhyolite, dacite. Some emplaced as submarine slides.*

Slbt — *Dark green and maroon basaltic block and lapilli tuff. Massive to well bedded.*

Slv — *Devitrified vitrophyre and autobreccia. Rhyolite Hydrothermally altered. Massive to flowbanded. Domes, flows, dikes.*

Slb — *Basalt flows. Altered to chlorite, epidote, albite.*

EDMUNDS FORMATION

Ses — *Grey mudstone, shale, argillite, chert, and bedded tuff. Brachiopods. pelecypods, gastropods, ostracodes, trilobites, corals.*

Set — *Maroon, purple, green lithic crystal lapilli tuff and tuff breccia with local red mudstone beds. Rhyolite and dacite. Some include basalt fragments. Generally well bedded and waterlaid.*

Setb — *Maroon, white, pink, purple tuff breccia. Rhyolite and dacite locally with basalt fragments. Massive, locally grading up into bedded tops and down into mixed fragments and mudstone. Emplaced as submarine slides.*

Seb — *Maroon basalt flows. Hydrothermally altered.*

Sev — *Devitrified vitrophyre and autobreccia. Massive to flowbanded. Domes, dikes, concordant lenses. Rhyolite and dacite.*

Sebx — *Maroon and white coarse breccia and agglomerate. Devitrified vitrophyre and autobreccia locally with basalt blocks and pumice lapilli. Local blocks of shale and bedded tuff. Many vitrophyre and diabase dikes. Probably vents for most of Edmunds volcanics.*

Sdev *Domes with local flowbanding and autobreccia. Separates Dennys formation from lower part of Edmunds formation.*

DENNYS FORMATION

Sdt — *Bedded tuff, lapilli tuff, pebbly volcanic conglomerate, tuffaceous shale, argillite, chert. Mixed basalt and keratophyre fragments. Brachiopods, pelecypods, trilobites, corals.*

Sdbt — *Basaltic agglomerate and lapilli tuff. Massive to thickly bedded.*

Sdb — *Thin basalt flows. Altered to chlorite, epidote, albite.*

Sdtb — *White to pink tuff breccia and flow breccia. Keratophyre and rhyolite.*

Sdv — *Devitrified vitrophyre and autobreccia. Massive to flowbanded. Keratophyre and rhyolite. Domes, dikes, and concordant lenses.*

FAULT CONTACT

QUODDY FORMATION

Sqs — *Grey to black siliceous shale, argillite, and a few tuff beds. Graptolites.*

Su — *Silurian undifferentiated. Shale, argillite, bedded tuff. Graptolites reported by Bastin and Williams (1914).*

INTRUSIVE ROCKS

gr — *Hornblende biotite granite. Devonian?*

d — *Diabase and gabbro. Dikes, sills, concordant lenses, and irregular bodies. Hydrothermally altered to chlorite, epidote, albite. Silurian and Devonian.*

a — *Basaltic andesite of Mt. Tom. Hydrothermally altered. Silurian or Lower Devonian.*

SYMBOLS

Contact located. Contact inferred. Fault located. Fault inferred. Fault projected.

Dip and strike of bedding. Vertical intense fracture cleavage.

SCALE 1:48000

2 1 0 2 MILES

2000 0 2000 4000 6000 8000 10000 12000 14000 FEET

2 1 0 2 KILOMETER

CONTOUR INTERVAL 20 FEET

GEOLOGIC MAP AND CROSS SECTIONS OF THE EASTPORT QUADRANGLE, MAINE

by
Olcott Gates

1975